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Optimization of Wire Electro Discharge Machining Parameters to Achieve Better MRR and Surface finish

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Abstract

This paper focuses on the investigation of effect of process parameters on the responses such as MRR and surface roughness of $Ti_{50}Ni_{40}Cu_{10}$ SMA machined by WEDM using the Taguchi techniques to obtain optimum machining process parameters. A number of experiments were conducted using the L_{18} orthogonal array on an Electronica WEDM. A combined technique using orthogonal array and analysis of variance was employed to investigate the contribution and effects of peak current, pulse on time, pulse off time and wire feed on the MRR and surface roughness. The results showed that peak current, pulse on time and servo voltage is the major significant effect on the MRR and surface roughness. Thereafter, optimal machining parameters were obtained by the analysis of mean.

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Keywords: $Ti_{50}Ni_{40}Cu_{10}$ SMA; L_{18} orthogonal array; MRR, surface finish

1. Introduction

A non conventional wire electro discharge machining process is suitable process to machine electrically conductive of difficult to machine materials of any intricate and complex shapes. The principle is on the removing of material by erosion and evaporation due to the thermal energy (electrical spark) (Ho et al. 2004). WEDM is evolved by making dies, press tools, and machining of micro parts with accurate and a better surface quality. Generally WEDM utilizes continuous travelling of brass wire electrode of 0.05mm to 0.3mm diameter to achieve a very small corner radius. The process parameters include in WEDM viz. peak current, pulse on time, pulse off time, servo

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voltage, wire feed, servo feed, wire tension and dielectric fluid pressure etc. which affecting the machining performance characteristics such as material removal rate (MRR) and surface finish. The MRR and surface finish decides the productivity and capability to machine materials. Unless optimum setting of process parameters causes the surface defects on the machined surface (Aspinwall et al. 2008). Optimization of process parameters is imperative to control the surface defects and desired performances to achieve.

TiNi shape memory alloys are unique among several materials, having pseudoelastic and shape memory property. These materials have a recoverable strain upto 8%. In general binary TiNi SMAs widely used as commercial and potential applications such as aerospace, automotive and biomedical etc. Ternary copper based TiNi SMAs have very good mechanical properties, dynamic properties, wear, corrosion and excellent fatigue properties Araújo et al. 2011, Gil et al. 2004, Nespoli et al. 2011). The little variation in the atomic percentage of nickel leads for changing the transformation temperature and reduces thermal hysteresis of the material and makes more ductile (Araújo et al. 2011, Lin et al. 2010). Due to these fascinating properties, applications are widened such as thermo-mechanical sensors, servomotors, actuators and better suitable in coupling and sealing [Rong et al. 2001, Shin et al. 2009, Wu et al. 2000). Hence machining of these materials is very much essential. Machining of these materials by conventional process is extensively difficult due to low thermal conductivity, high chemical reaction, rapid tool wear due to higher hardness, strain hardening effect and anti-sticking nature (Weinert and Petzoldt 2004, Lin et al. 2000). To overcome these difficulties WEDM process is selected in the present study. Over the years some of the researchers have contributed in the wire electro discharge machining of SMAs. The machining characteristics and shape recoverability of TiNiZr/Cr was studied by using WEDM. Electrode discharge energy is highly related to achieve maximum wire feed rate and it is also depend on the melting temperature and thermal conductivity of material. The longer pulse on time duration causes rough surface finish, increased recast layer thickness and higher surface hardness of the outer machined zone (Hsieh et al. 2009). The shape recoverability and machined surface hardness of NITINOL-60 have been investigated. They concluded that formation of recast layer on the machined surface cause changes in both the physical and mechanical properties of the alloy (LotfiNeyestanak and Daneshmand 2013). This research paper investigates the MRR and surface finish for WED-Machined $Ti_{50}Ni_{40}Cu_{10}$ SMA. Taguchi orthogonal array is employed to analyze the process parameters such as peak current, pulse on time, pulse off time, servo voltage and wire feed. Analysis of variance (ANOVA) is used to study the significant process parameter and percentage of contribution on the responses. The signal to noise ratio is used to analyze and to select optimum process parameters by the Analysis of mean (ANOM).

2. Material and method

2.1 Workpiece material

$Ti_{50}Ni_{40}Cu_{10}$ SMA was prepared by using vacuum arc melting process. Pure metal pieces from Titanium rods containing 99.2%, Nickel rods containing 99.89% and Copper with a purity of 99.84% were mixed according to the desired weight percentage into the copper mould melting chamber under vacuum. Prior to melting the chamber was pumped out to create a vacuum of 10-5 mbar and subsequently filled with high purity argon gas. This was repeated three times to remove the impurities present in the chamber. Further melting and remelting was carried out for six times in an argon atmosphere by the electric arc using tungsten electrode to achieve homogeneity of the alloy composition.

2.2 Taguchi method

Taguchi method is used to find the optimum setting of control factors to make the product or process insensitive to noise factors. Taguchi design is based upon the technique of matrix experiments, known as orthogonal arrays, which allow the simultaneous effect of numerous factors to be studied proficiently. The purpose of conducting an orthogonal experiment is to select the optimum level for each factor using analysis of means (ANOM) and to find the comparative significance of individual factor using analysis of variance (ANOVA) on the proposed performance characteristic. Taguchi suggests signal to noise (S/N) ratio as the objective function for matrix experiments (Phadke 1989, Ross 1996). Taguchi classifies objective functions into three categories, namely, smaller the better type, larger the better type and nominal the best type. The optimum level for a factor is the level that results in the highest S/N Ratio value in the experimental region.

3. Experimental details

In this study, five parameters, namely, peak current, pulse on time, pulse of time, servo voltage and wire feed were identified and the range of the each parameter was determined from the preliminary experiments. Experimentation was performed by using Taguchi mixed L18 orthogonal array (OA). Whereas peak current taken as two level and remaining parameters considered as three level were selected to study the combinational effect of parameters on the responses. The identified controllable parameters in WEDM of $Ti_{50}Ni_{40}Cu_{10}$ SMA experiments and their associated levels are presented in Table 1. The brass wire of 0.25 mm diameter was used as electrode; de-ionized water as dielectric fluid of pressure 12 kg/mm^2 were kept as constant throughout the investigation. The experiments were performed on 'Electronica Maxicut' as per L18 orthogonal array.

Table 1: Control parameters and their level

Code	Parameter	Level 1	Level 2	Level 3
IP	Peak current (A)	2	12	__
Ton	Pulse on time (μs)	120	125	130
Toff	Pulse off time (μs)	48	59	66
SV	Servo voltage (V)	20	50	80
WF	Wire feed (m/min)	5	10	15

3.1 Measurement of Surface roughness (Ra) and MRR

The surface roughness was measured as per JIS 2001 standard by using 'Mitutoyo' surface roughness tester. The average surface roughness (Ra), are considered for the current study. The surface roughness of the workpiece was measured at five different locations and the average was taken as the process response. The cutoff length of 0.8 mm was selected and evaluation length of 4 mm was used to measure the surface roughness with a stylus speed of 0.25 mm/s.

The material removal rate (MRR) is calculated by using equation (1).

$$MRR = VcXbXh \tag{1}$$

Where Vc is machining speed in mm/min
b - Width of cut in mm b = 2Wg + d
Where Wg is a spark gap in mm and d is the diameter of wire in mm.
h- Height of job in mm.

4. Results and Discussion

The experimental results of mean and their associated S/N ratio values are shown in the Table 2. The responses were analyzed by the Analysis of variance (ANOVA), main effect plots and interaction plots. The optimum values were evaluated by using Analysis of mean (ANOM) of S/N ratio values considering the higher S/N ratio value.

Table 2: Experimental plan and results

Sl.No.	IP	Ton	Toff	SV	WF	MRR	S/N ratio	Ra	S/N ratio
1	2	120	40	20	5	1.59344	4.04671	1.98	-5.9333
2	2	120	50	40	10	1.56145	3.87056	1.6	-4.0824
3	2	120	60	60	15	1.5434	3.76957	1.295	-2.2454
4	2	125	40	20	10	2.95481	9.41059	2.025	-6.1285
5	2	125	50	40	15	2.624	8.37928	1.92	-5.666
6	2	125	60	60	5	2.27483	7.13898	1.836	-5.2775
7	2	130	40	40	5	5.27105	14.4379	1.92	-5.666
8	2	130	50	60	10	5.64692	15.0362	1.764	-4.93
9	2	130	60	20	15	5.89199	15.4052	2.18	-6.7691
10	12	120	40	60	15	3.38087	10.5806	1.955	-5.8229
11	12	120	50	20	5	6.49286	16.2487	2.52	-8.028
12	12	120	60	40	10	5.4503	14.7284	2.065	-6.2984
13	12	125	40	40	15	7.33585	17.309	2.305	-7.2534
14	12	125	50	60	5	6.0385	15.6186	2.05	-6.2351
15	12	125	60	20	10	7.39347	17.377	2.635	-8.4156
16	12	130	40	60	10	7.38118	17.3625	2.605	-8.3162
17	12	130	50	20	15	7.81176	17.855	3.74	-11.457
18	12	130	60	40	5	7.2353	17.1891	2.88	-9.1878

4.1 Analysis of variance (ANOVA)

The use of S/N ratio is to measure responses to develop products and processes insensitive to noise factor (Cochran and Cox 1992). This indicates the degree of predictable responses of product or process in the presence of noise factors. The parameters setting with highest S/N ratio yield optimum value with minimum variance. The experimental results and their S/N ratio values are shown in Table 2. Larger the better function is used for MRR to increase productivity and smaller the better is to surface roughness (Ra) characteristics to find arithmetic mean average surface roughness (Ra). The optimum level for a factor is the level that results in the highest S/N ratio value in the experimental domain.

The main purpose of ANOVA is to identify the effect of individual and interaction factors. Table 3 and 4 shows the analysis of variance for MRR and surface roughness (Ra) respectively. This analysis is carried out for 5% significance level, i.e. 95% confidence level. Calculated F values are more than the table value: $F_{0.05,\ 1,\ 6\ =\ 6.61}$ and $F_{0.05,\ 2,\ 6\ =\ 5.14}$ at 95% confidence level. Based on the F-ratio, determines the process parameter is significant or not. From Table 3 it can be concluded that peak current, pulse on time and the interaction effect of peak current × pulse on time are the significant parameters. The pulse off time, servo voltage and wire feed have no significant effect on the MRR. It is observed from the Table 4, peak current, pulse on time, servo voltage and peak current × pulse on time are the significant parameters affecting surface roughness and remaining parameters are insignificant. This is based on the calculated F value is greater than the tabulated F value for 95% confidence level. However it also observed from the calculation of percentage of contribution, the peak current is a major influencing factor which is of 45-48% contribution on the MRR and Surface roughness followed by pulse on time of 21-35% and servo voltage having 21.84% contribution on the surface roughness. The IP×Ton have a contribution of 9.64% and 4.37% on the MRR and surface roughness respectively.

Table 3: Analysis of Variance for MRR

Source	DF	SS	MS	F	P	P%
IP	1	218.91	218.91	136.64	0	48.33
Ton	2	161.63	80.81	50.45	0	35.23
Toff	2	1.27	0.63	0.4	0.68	----
SV	2	9.89	4.94	3.09	0.12	1.48
WF	2	1.76	0.88	0.55	0.60	----
IP*Ton	2	46.55	23.27	14.53	0.005	9.64
Residual Error	6	9.61	1.60			5.41
Total	17	449.65				100

S = 1.266   R-Sq = 97.9%   R-Sq(adj) = 93.9%

Table: 4 Analysis of Variance for Surface Roughness (Ra)

Source	DF	SS	MS	F	P	P%
IP	1	32.85	32.85	98.14	0	45.13
Ton	2	16.15	8.07	24.13	0.001	21.50
Toff	2	0.40	0.20	0.61	0.574	---
SV	2	16.40	8.20	24.51	0.001	21.84
WF	2	0.38	0.19	0.58	0.589	---
IP*Ton	2	3.82	1.91	5.71	0.041	4.37
Residual Error	6	2.00	0.33			7.16
Total	17	72.04				100

S = 0.5786   R-Sq = 97.2%   R-Sq(adj) = 92.1%

4.2 Main effect plots

The main effect plots are drawn by considering the mean average of the parameters of their each level of raw data. It is observed from the Fig. 1 that the MRR increased with increase in peak current and pulse on time due to higher discharge energy. The energy content of the spark is dependent on the multiplication of peak current and pulse on time. Higher in peak current or pulse on time causes increase in discharge energy. This leads to melts and vaporizes more amount of workpiece material cause for greater MRR (Kumar et al. 2013). Increase in servo voltage caused to decrease in MRR, because of reduced the cutting speed due to widened spark gap. At lower servo voltage (20V) the spark gap is narrow and it leads to higher discharge energy and intensity of spark, it melts and evaporates the workpiece material. The pulse off time and wire feed are not much influencing the MRR due to the indistinguishable cutting speed was observed. Fig. 2 depicts the effect of process parameters on the surface roughness (Ra).

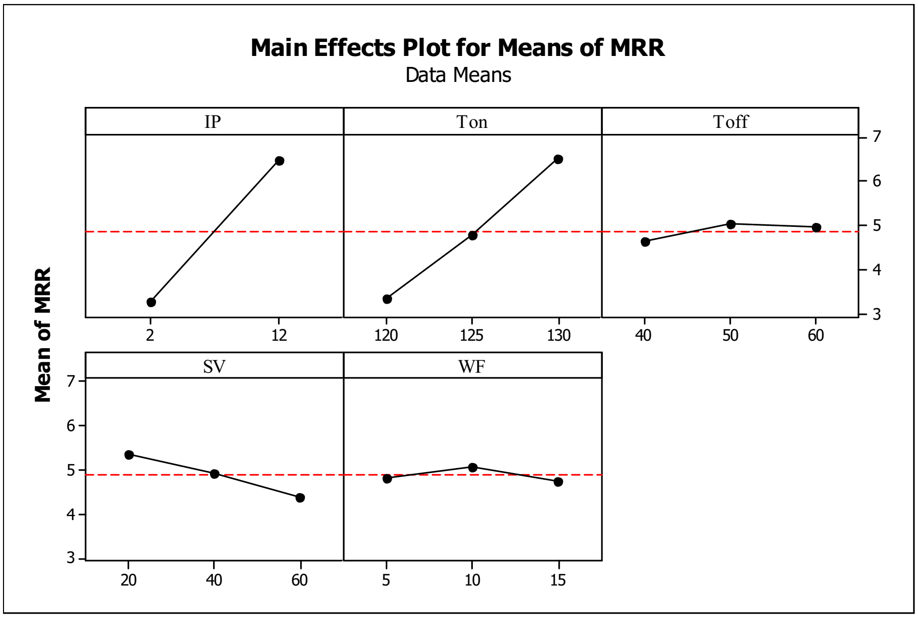

Fig.1. Main effect plots for MRR

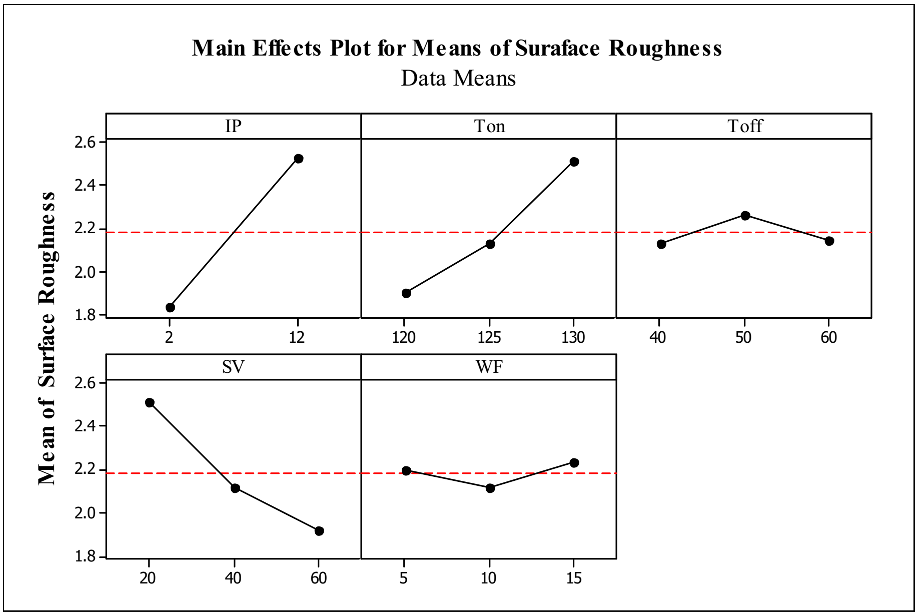

Fig.2. Main effect plots for surface roughness (Ra)

4.3 Interaction plots

Figure 3 and 4 reveals the interaction plots for MRR and surface roughness. It is observed that the MRR is increased not only by the effect of peak current or pulse on time, it is the combination effect of pulse on time and peak current. As it is observed from the Fig. 4 the MRR increased with respect to increase in peak current or pulse on time. For lower peak current of 2A MRR is of 1.5-26 mm3/min for a pulse time of 120-125µs and for higher pulse on time say 130 μs the MRR increased very drastically due to the combination of greater discharge energy with larger melting duration of spark energy. From the Fig. 5 it is analyzed that for lower peak current of 2A the surface roughness was not affected by the increase in pulse on time. For higher peak current of 12A and increase in pulse on time causes formation of larger craters, pockmarks, the pits surface, larger amount of settling of globules of melted droplets leads for higher surface roughness was observed from the SEM micrographs as shown in Fig. 5.

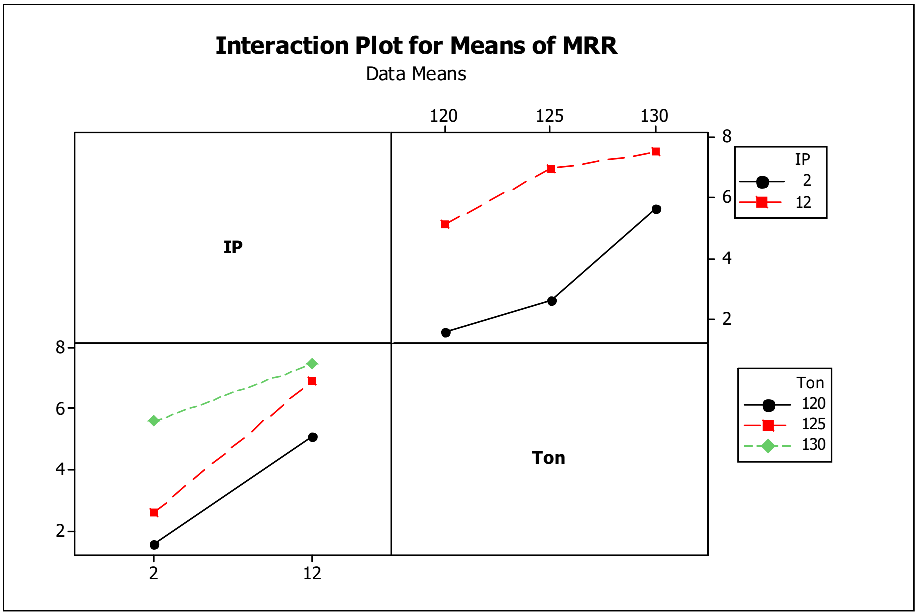

Fig.3. Interaction effect of peak current and pulse on time on MRR

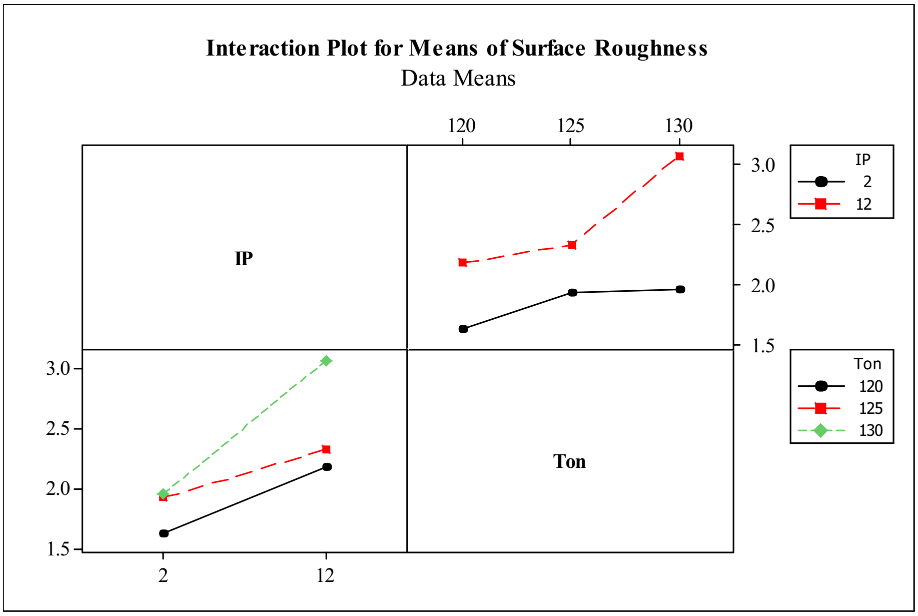

Fig.4. Interaction effect of peak current and pulse on time on Surface roughness

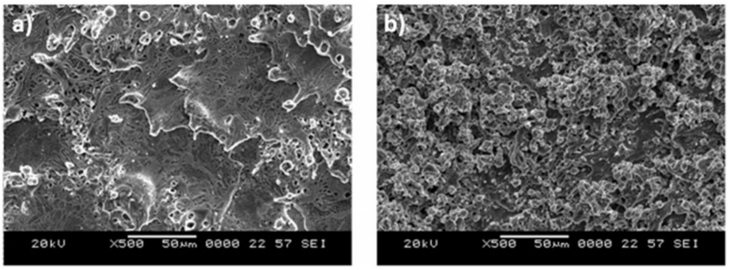

Fig. 5. Machined surface SEM micrograph (a) Trial No.7 (Ip-2A, Ra-1.92µm)
(b) Trial No.13 (Ip-12A, Ra-2.3µm)

5. Evaluation of S/N Ratios for Optimal Design

The mean response refers to the average values of the performance characteristics for each variable at different levels. The average values of S/N data for MRR and surface roughness were obtained separately and are given in Tables 5 and 6. These values are plotted in main effect plots seen in Figs. 1 and 2. In Taguchi method, higher the levels for S/N ratio, the better the overall performance, it means that the factor levels with the highest S/N ratio value should always be selected. Regardless of the lower-the-better/higher-the-better quality characteristic, the greater S/N ratio corresponds to the smaller variance of the response characteristics around the target value.

Based on the S/N ratio and ANOVA, the optimal input variables for MRR are the peak current at level 2, the pulse on time at level 3, pulse off time at level 2, servo voltage at level 1and wire feed at level 2 (Table 5). It is clear from the Table. 6 that the peak current at level 1, the pulse on time at level 1, pulse off time at level 3, servo voltage at level 3 and wire feed at level 1 are the best choice in terms of the surface roughness.

Table : 5 Response Table for Signal to Noise Ratios for MRR

Level	IP	Ton	Toff	SV	WF
1	9.055	8.874	12.191	13.391	12.447
2	16.030	12.539	12.835	12.652	12.964
3		16.214	12.601	11.584	12.216
Delta	6.975	7.340	0.644	1.806	0.748
Rank	2	1	5	3	4

Table: 6 Response Table for Signal to Noise Ratios for surface roughness

Level	IP	Ton	Toff	SV	WF
1	-5.189	-5.402	-6.520	-7.789	-6.721
2	-7.891	-6.496	-6.733	-6.359	-6.362
3		-7.721	-6.366	-5.471	-6.536
Delta	2.702	2.319	0.368	2.318	0.359
Rank	1	2	4	3	5

6. Confirmatory experiments

Confirmation experiments were designed as per the optimum levels predicted by the analysis of means. The experiments were performed to validate the optimization L18 Taguchi experiments. The predicted values and the experimental values for MRR and surface roughness were as shown in the Table 7. It is clearly shows that error between confirmatory and predicted value is less than 6% error. It confirms that excellent reproducibility of the results and also confirms that optimized process parameters and response values are in close agreement with experimentally obtained values.

Table 7 : Confirmatory results for MRR and Ra

	MRR	Ra
Level	IP2Ton3Toff2SV1WF2	IP1Ton1Toff1SV3WF1
Predicted	8.279	1.326
Experimental	8.012	1.25
Error	3.22%	5.73%

7. Conclusions

The wire electro discharge machining properties of $Ti_{50}Ni_{40}Cu_{10}$ at% SMA have been investigated using the Taguchi technique. Five important process parameters, peak current, pulse on time, pulse off time, servo voltage and wire feed have been studied. The following conclusions drawn from the results:

- Peak current, pulse on time and servo voltage are major significant factors affecting the MRR and surface finish during machining of $Ti_{50}Ni_{40}Cu_{10}$ at% SMA. Pulse off time and wire feed had no significant on the responses.
- The optimum levels of the process parameters have been established for getting the higher MRR and better surface finish using L18 orthogonal array of experiments.
- The error percentage is 3.22% for MRR and 5.73% for surface finish which is less than 10% for the acceptance. Lower peak current is suitable to produce better surface finish evident from the SEM micrograph.

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